# ELECTROPHORETIC DISPLAY PANEL HAVING ROTATABLE PARTICLES

The invention relates to a display panel for displaying a picture.

The invention also relates to a display device comprising such a display panel.

The invention further relates to a method of driving such a display panel.

A display panel for displaying a picture is disclosed in US 5,389,945.

The disclosed display panel is a gyricon display, also called the twisting ball display, which offers a technology for making a form of electronic paper. Briefly, a gyricon display is an addressable display made up of a multiplicity of optically anisotropic balls, each of which can be selectively rotated to present a desired face to an observer.

More in detail, the disclosed display panel comprises a host layer loaded with small balls rotatable in cavities therein. The host layer may be an elastomer, such as silicone rubber, in sheet form, having dispersed therein a high density of dielectric balls. Each ball is fabricated so that its hemispheres bear contrasting colors, preferably black on one side and white on the other, and will exhibit differential surface charges in an electrical field. Each ball is contained in a spherical cavity, slightly larger than the ball, with the space between the ball and the cavity filled with a dielectric liquid so that the ball is free to rotate therein. Upon the application of an electric field of a given polarity and of a potential higher than a threshold value, the balls will line up so that their black sides all face in one direction. When viewed from that direction, the display panel will appear to be black. Conversely, reversing the polarity of the electric field will cause the balls to rotate 180 degrees, so that their white sides face in the viewing direction and the display panel will appear to be white. However, the display panel has a relatively low number of attainable optical states.

It is an object of the invention to provide a display panel of the kind mentioned in the opening paragraph which is able to have a relatively large number of attainable optical states for displaying the picture.

To achieve this object, the invention provides an electrophoretic display panel for displaying a picture comprising

- a pixel having
  - an electrophoretic medium comprising particles, each particle having in operation an electrical multipole for being able to be moved and rotated and at least two surface portions having dissimilar optical properties, and
  - an optical state depending on a position and an orientation of the particles, and
- a particle controller arranged to enable a movement and a rotation of the particles to one of the positions and one of the orientations, respectively, for displaying the picture.

As a consequence of the medium being an electrophoretic medium the particles can both move and rotate in the medium. The particle controller is able to move the particles because each particle has, in operation, an electrical multipole. As an example, the particle controller is able to apply an electrical field having a spatially non-uniform gradient. The electrical multipole may be permanent or the multipole may be induced in operation for example by an alternating electric field. Furthermore, the particle controller is able to rotate the particles because each particle has, in operation, an electrical multipole. The optical state of the pixel depends on the orientation of the particles, each particle having at least two surface portions having dissimilar optical properties, as well as on the position of the particles. As a result of these dependencies the number of attainable optical states for displaying the picture is relatively large. As an example: for a given orientation of the particles, the optical state of the pixel can be changed by changing the position of the particles. This is in contrast to the display panel disclosed in US 5,389,945, where for a given orientation of the particles, the optical state of the pixel can not be changed as the position of the particles is fixed.

If, furthermore, for the display panel according to the invention the electrical multipole comprises an electrical dipole, the particle controller is able to rotate each particle by applying an electrical field having a spatially uniform gradient, which can relatively simply be achieved. If, furthermore, each particle has a net charge for contributing to the ability of the particle to move, the particle controller is able to move each particle by applying an electrical field having a spatially uniform gradient, which can relatively simply be achieved.

In an embodiment each particle has a substantially spherical shape and two hemispheres, which have dissimilar optical properties and substantially opposite charges. Then, the particles can relatively easily be manufactured. An example is the Gyricon particles from the Xerox company.

In an embodiment the particle controller is arranged to enable the movement of the particles so as to locally control the density of the particles.

There are many concepts possible whereby the particles are moved and rotated in the electrophoretic medium, e.g. the movement and rotation may be simultaneously, or the particles may be rotated prior to the movement. If the particle controller is arranged to enable the movement of the particles prior to the rotation of the particles, then the accuracy of the picture is improved. If, furthermore,

- the pixel comprises a reservoir portion substantially non-contributing to the optical state of pixel,
- the pixel comprises an optical active portion substantially contributing to the optical state of pixel,
- the particles in the optical active portion are able to rotate between extreme orientations,
- the movement of the particles comprises
  - a reset-movement of the particles into the reservoir portion, and subsequently
  - a picture-movement of the particles to the position for displaying the picture, and
- the rotation of the particles comprises
  - a reset-rotation of the particles in the optical active portion to one of the extreme orientations, and subsequently
  - a picture-rotation of the particles in the optical active portion to the orientation for displaying the picture, then the accuracy of the picture is further improved.

In another embodiment each particle has more than two surface portions having dissimilar optical properties, for instance each particle has a red, a green and a blue surface portion, each particle has a white, a black and a colored surface portion or each particle has a red, a green, a blue and a white surface portion. Preferably, the surface portions on each particle have substantially equal areas.

In another embodiment the electrophoretic medium also has a second type of particles being able to be moved and rotated. Each particle of the second type of particles has one or more surface portions having dissimilar optical properties with respect to the first type of particles, for instance the first type of particles have a green and a red surface portion, whereas the second type of particles have a blue and a black surface portion. Preferably the surface portions have substantially equal areas.

In another embodiment the display panel comprises a super pixel comprising
- the pixel,

- a further pixel having particles having at least two surface portions having dissimilar optical properties and dissimilar optical properties with respect to the surface portions of the particles of the pixel, and
- a still further pixel having particles having at least two surface portions having dissimilar optical properties and dissimilar optical properties with respect to the surface portions of the particles of the pixel and the particles of the further pixel.

Then color combinations for the super pixel are possible which can be advantageously used in a color display panel.

In another embodiment, the display panel is an active matrix display panel.

Another aspect of the invention provides a display device comprising an electrophoretic display panel as claimed in claim 10.

Yet another aspect of the invention provides a method of driving an electrophoretic display panel as claimed in claim 11.

These and other aspects of the display panel of the invention will be further elucidated and described with reference to the drawings, in which:

Figure 1 shows diagrammatically a front view of an embodiment of the display panel;

Figure 2 shows diagrammatically a cross-sectional view along II-II in Figure 1;

Figure 3 shows several options of coloring of the surface portions;

Figure 4 shows diagrammatically a cross-sectional view along II-II in Figure 1 of another embodiment of the display panel;

Figure 5 shows diagrammatically a cross-sectional view along II-II in Figure 1 of another embodiment of the display panel; and

Figure 6 shows diagrammatically a cross-sectional view along VI-VI in Figure 1 of another embodiment of the display panel.

In all the Figures corresponding parts are referenced to by the same reference numerals.

Figures 1 and 2 show an example of the display panel 1 having a first substrate 8, a second transparent opposed substrate 9 and a plurality of pixels 2. Preferably, the pixels 2 are arranged along substantially straight lines in a two-dimensional structure. Other arrangements of the pixels 2 are alternatively possible, e.g. a honeycomb arrangement. In an active matrix embodiment, the pixels 2 may further comprise switching electronics, for example, thin film transistors (TFTs), diodes, MIM devices or the like.

An electrophoretic medium 5, having particles 6 in a transparant fluid, is present between the substrates 8,9. The surface 15 of the first substrate 8 facing the second substrate 9 may be reflective or have any color. Electrophoretic media 5 are known per se from e.g. US 2002/0180688, whereas the particles 6 are known per se from e.g. US 5,389,945 and US 4,126,854, these documents being incorporated by reference herein. Each particle 6 has in operation an electrical multipole for being able to be moved and rotated. The multipole results from differential surface charges in an electrical field. The particles 6 may be dielectric balls, e.g. each about 15 to 30 microns in diameter. Each ball is fabricated to have at least two surface portions having dissimilar optical properties. A first one of the surface portions may have any color, whereas another one of the surface portions may have any color different from the color of the first one. The color of the first one of the surface portions is for instance red, green, blue, yellow, cyan, magenta, white or black.

In Figure 3 several options of coloring of the surface portions are shown, e.g each particle has a red (a1) and a green (a2) surface portion, each particle has a white (b1, c1), a black (b2,c2) and a colored (b3,c3) surface portion, or each particle has a red (d1), a green (d2), a blue (d3) and a white (d4) surface portion.

The particles 6 may e.g. have hemispheres 50,51 bearing contrasting colors, e.g. back on one side and white on the other. The particles 6 occupy a position in the pixel 2, and are able to move. The pixel 2 has a viewing surface 91 for being viewed by a viewer. The optical state of the pixel 2 depends on a position and an orientation of the particles 6.

The particle controller, having electrodes 10,11,20,21 for receiving potentials from the drive means 100, is arranged to enable a movement and a rotation of the particles 6 to one of the positions and one of the orientations, respectively, for displaying the picture. Each one of the electrodes 10,11,20,21 may have a substantially flat surface facing the particles 6. The geometry and potentials may be chosen such that substantially homogeneous

electric fields can be generated between the electrodes 10,11 and between the electrodes 20,21.

In an example, consider the particles 6 to have a red and a green hemisphere 50,51, i.e. the particles 6 are red on one side and green on the other. The red hemisphere 50 is negatively charged and the green hemisphere 51 is positively charged. As a result of this charge distribution the particle 6 has a permanent multipole, comprising a dipole. Furthermore, consider the magnitude of the negative charge to be larger than the magnitude of the positive charge resulting in the particle 6 having a net charge being negative. The net charge contributes to the ability of the particle 6 to move. Furthermore, electrode 21 and the fluid are transparent and the surface 15 of the first substrate 8 is blue. Consider the pixel layout of Figure 2.

To obtain an optical state being red, firstly, the particles 6 are brought in their distributed state in the pixel 2 by appropriately changing the potentials received by the electrodes 10,11. Subsequently, the particles 6 are oriented so that their red sides all face the viewing surface 91 by appropriately changing the potentials received by the electrodes 20,21. As a result the optical state of the pixel 2 is red.

To obtain an optical state being green, firstly, the particles 6 are brought in their distributed state in the pixel 2 by appropriately changing the potentials received by the electrodes 10,11. Subsequently, the particles 6 are oriented so that their green sides all face the viewing surface 91 by appropriately changing the potentials received by the electrodes 20,21; the polarity of the electric field between the electrodes 20,21 being opposite to the polarity for obtaining a red pixel 2. As a result the optical state of the pixel 2 is green.

To obtain an optical state being blue, the particles 6 are brought in their collected state near the surface of electrode 10 or 11, by appropriately changing the potentials received by the electrodes 10,11. As a consequence, the particles 6 are substantially outside the light path. Therefore, the optical state of the pixel 2 is blue, as the surface 15 of the first substrate 8 is blue.

Intermediate optical states are also possible. In an example, the particles 6 have a portion of their red and green hemispheres 50,51 oriented towards the viewing surface 91 which results in an optical state being intermediate between red and green, i.e. yellow, orange etc. In another example, only a small number of particles 6 are distributed in the pixel 2 thereby not fully covering the blue surface 15 of the first substrate 8, whereas the small number of particles 6 have their red sides facing the viewing surface 9, which results in an optical state

being intermediate between red and blue, i.e. purple. A further example is a combination of the previous two examples.

Figure 4 shows another embodiment. This embodiment is similar to the previous embodiment shown in Figure 2. However, in this embodiment, the pixel 2 has a reservoir portion 510 substantially non-contributing to the optical state of the pixel 2, because of the black matrix 513 shielding the reservoir 510 from the viewer. The reservoir 510 has a data electrode 512 and a reset electrode 511. The data electrode 512 may be connected via a thin film transistor TFT to data drivers in an active matrix, while the reset electrode 511 may be common for a plurality of pixels 2 or even for the entire display panel 1. Furthermore, barriers 514a,514b forming pixel walls may separate pixels 2 from each other. The pixel 2 has an optical active portion 530 substantially contributing to the optical state of the pixel 2. The orientations of the particles 6 in the optical active portion 530 comprise extreme orientations, depending on the multipole of the particles 6 and the positions of electrodes 20,21 for orienting the particles 6. In this example, the particles 6 in the optical active portion 530 have a first extreme orientation if the particles 6 in the optical active portion 530 are oriented, lined up, so that their red sides all face the viewing surface 91 and the particles 6 in the optical active portion 530 have a second extreme orientation if the particles 6 in the optical active portion are oriented, lined up, so that their green sides all face the viewing surface 91. In this embodiment, the movement of the particles 6 has a reset-movement of the particles 6 into the reservoir 510, and subsequently a picture-movement of the particles 6 to the position for displaying the picture, and the rotation of the particles 6 in the optical active portion 530 has a reset-rotation of the particles 6 to one of the extreme orientations, and subsequently a picture-rotation of the particles 6 in the optical active portion 530 to the orientation for displaying the picture.

To obtain an optical state being red, firstly, the particles 6 are brought into the reservoir 510 (this being the reset-movement) by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 0 Volts, 0 Volts, 10 Volts and 5 Volts, respectively. Secondly, the particles 6 are brought into their position for displaying the picture (this being the picture-movement) by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 5 Volts, 5 Volts, 4 Volts and 3 Volts, respectively. The number of particles 6 brought into the optical active portion 530 can be selected by appropriate potentials received by the electrodes 20,21,511,512 and the time during which the potentials are applied. The particles 6 in the reservoir 510 are kept in the reservoir 510 by collecting

them near the surface of electrode 511 by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 0 Volts, 0 Volts, 2 Volts and 0 Volts, respectively. Thirdly, the particles 6 in the optical active portion 530 are rotated to one of the extreme orientations (this being the reset-rotation), e.g. red, by appropriately changing the potentials received by the electrodes 20,21, e.g. the electrodes 20,21 receive 0 Volts and 2 Volts, respectively. The subsequent picture-rotation of the particles 6 in the optical active portion 530 to the orientation for displaying red may in this case be absent because as a consequence of the reset-rotation the particles 6 in the optical active portion 530 are already oriented so that their red sides all face the viewing surface 91. As a result the optical state of the pixel 2 is red. The intensity is determined by the number of particles 6 in the optical active portion 530.

To obtain an optical state being green, firstly, the particles 6 are brought into the reservoir 510 (this being the reset-movement) by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 0 Volts, 0 Volts, 10 Volts and 5 Volts, respectively. Secondly, the particles 6 are brought into their position for displaying the picture (this being the picture-movement) by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 5 Volts, 5 Volts, 4 Volts and 3 Volts, respectively. The number of particles 6 brought into the optical active portion 530 can be selected by appropriate potentials received by the electrodes 20,21,511,512. Thirdly, the particles 6 in the optical active portion 530 are rotated to one of the extreme orientations (this being the reset-rotation), e.g. red, by appropriately changing the potentials received by the electrodes 20,21. Fourthly, the particles 6 in the optical active portion 530 are rotated to the orientation for displaying green (this being the picture-rotation), by appropriately changing the potentials received by the electrodes 20,21. As a consequence of the picture-rotation the particles 6 in the optical active portion 530 are rotated so that their green sides all face the viewing surface 91. As a result the optical state of the pixel 2 is green.

To obtain an optical state being blue the particles 6 are brought into the reservoir 510 by appropriately changing the potentials received by the electrodes 20,21,511,512, e.g. the electrodes 20,21,511,512 receive 0 Volts, 0 Volts, 10 Volts and 5 Volts, respectively. As a result the optical state is blue, being the color of the surface 15. Furthermore, it is clear that intermediate optical states are also possible.

Figure 5 shows another embodiment. This embodiment is similar to the previous embodiment shown in Figure 4. However, in this embodiment, the electrophoretic

medium has a second type of particles 7 which are able to be moved and rotated. The particles 7 having a net charge being positive. The pixel 2 has a second reservoir portion 520 for the second particles 7 substantially non-contributing to the optical state of the pixel 2, as the black matrix 513 shields the second reservoir 520 from the viewer. The second reservoir 520 has a data electrode 521 and a reset electrode 522. Furthermore, barriers 514a,514b forming pixel walls may separate pixels 2 from each other. The pixel 2 has an optical active portion 530 substantially contributing to the optical state of the pixel 2. The orientations of the particles 6,7 in the optical active portion 530 comprise extreme orientations, depending on the multipole of the particles 6,7 and the positions of electrodes 20,21 for orienting the particles 6,7. As an example, the first type of particles 6 have a green and a red surface portion, whereas the second type of particles 7 have a blue and a black surface portion. The surface 15 is white. Similar to the previous embodiment, the first and/or the second type of particles can be brought into or out of the optical active portion 530. Attainable optical states are red, green, blue, black and white and intermediate optical states.

In case a super pixel 600 consists of a number of pixels 2, the optical state of the super pixel 600 depends on the optical states of the associated pixels 2. Some preferred color combinations will be shown which can be advantageously used to create a full color display panel 1 using the principle of rotating multi-colored particles. As different pixels 2 associated with the super pixel 600 require filling with separate fluids/particles, manufacturing methods such as ink-jet printing will be suitable. Consider the super pixel 600 to consists of three adjacent pixels 2a,2b,2c, see Figure 6.

In this embodiment, pixels 2a,2b,2c are considered having respective particles 6a,6b,6c which have a colored hemisphere and a black hemisphere, e.g. particles 6a are blue on one side and black on the other, particles 6b are green on one side and black on the other, particles 6c are red on one side and black on the other. Furthermore, surfaces 15a,15b,15c are white. In this manner, it is possible to have an optical state of the super pixel being between black and white, and also being colored at up to 1/3 of the maximum intensity by selectively rotating the particles 6a,6b,6c in each one of the three pixels 2a,2b,2c. This embodiment has the advantage that the brightness of the display panel 1 may be increased at the expense of the viewing angle by defining the degree of scattering and mirroring of the "white" surfaces 15a,15b,15c (as is common for the so-called diffusing reflectors used in reflective LCDs).

In a similar manner, particles 6a,6b,6c are considered which have a colored hemisphere and a white hemisphere. Furthermore, surfaces 15a,15b,15c are black. In this manner, it is possible to have an optical state of the super pixel being between black and

white, and also being colored at up to 1/3 of the maximum intensity by selectively rotating the particles 6a,6b,6c in each one of the three pixels 2a,2b,2c. This embodiment has the advantage that the contrast of the display panel 1 may be extremely good due to the absorbing black surfaces 15a,15b,15c.

In the previous two variants the function of the color of surfaces 15a,15b,15c may be replaced with a fluid of the relevant color. This has the advantage that the creation of the color of surfaces 15a,15b,15c is saved.

In another embodiment, particles 6a,6b,6c are considered which have hemispheres of two primary colors and pixels 2a,2b,2c with either a white or a black surface 15a,15b,15c. In this manner, it is possible to have an optical state of the super pixel 600 being colored at up to 2/3 of the maximum intensity by selectively rotating the particles in two individual pixels (i.e. create red by filling the left hand and central pixel with particles and rotating all particles so that the red side faces the viewer). Also bright mixed colors will be obtainable by filling all three pixels 2a,2b,2c with suitable amounts of particles 6a,6b,6c and rotating the particles 6a,6b,6c as required.

In the case of black surfaces 15a,15b,15c, an excellent contrast will be realised, but the white intensity will be only 1/3 of the maximum. In the case of a white surfaces 15a,15b,15c, an excellent white intensity will be realised, but the contrast ratio will only be 3:1.